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METHODS OF MEASUREMENT
OF DISCHARGE AND EQUIPMENT
FOR SURVEY IN THE NILE BASIN

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METHODS OF MEASUREMENT OF DISCHARGE AND
EQUIPMENT FOR SURVEY IN THE NILE BASIN.

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1. The dependence of Egypt on the Nile has led to intensive studies of the quantities of water carried by the Main stream and its tributaries throughout the year. These studies may be said to have begun at a very early date, as the ancient Egyptians recorded river levels on Nilometers some of which still remain. The Nilometer on Roda Island, Cairo dates back to 860 A.D. and records on its predecessors for 220 years earlier exist though with many gaps. But previous to the present century, there was very little detailed knowledge about the Nile supply and its origin.

2. In the Nile Basin all river flow is measured and not estimated. Estimation from climatic and topographical data was made in the early days in the reconnaissance of the Basin. The rain water finding its way into the Nile is far more accurately determined from the measured discharges than from any deductions based on rainfall or from comparison with similar river regimes.

3. In Egypt and the Sudan Evaporimeters of the Piche type in meteorological stations are used and experiments have been carried with a view of correlating their readings with floating tanks of different sizes.

A reduction factor of 0.50 was found for the reduction of "Piche" to a standard tank 2 metres square.

4. The scientific study of the hydrology of the Nile began in 1902 with the introduction of current meters. Previously they had been measured by the less accurate "float" method. By 1912 rainfall, gauge and permanent discharge stations had been established at some of the most important points on the river. Since then they have been continued and extended to the farthest parts of the Nile Basin and now include all the tributaries of the Nile of any importance except those in Ethiopia.

Measurement of the discharge of the Nile by currentmeter:

5. Since the quantity of water flowing in the river is the funda-

mental quantity on which all irrigation and irrigation projects are based, it is evident that measurement of the discharge is the most important of all measurements on the Nile. The method adopted in the Nile is to choose a cross-section of the river on a straight uniform reach and measure the depth at two points close to each bank and at 20 or more points equally spaced across the river. At the same time the velocity is measured with a currentmeter at one or more depths. The width of the river and distances between the soundings are determined in the case of the narrower tributaries by stretching a marked wire rope across the stream and this also serves to hold the boat in place. In the case of the Main Nile and the wider tributaries the work is done from a launch anchored at each observation point and whose position is fixed by box-sextant observations on beacons on both banks.

Requisite conditions for the establishment of a discharge site (1):

6. A discharge station should be established after a thorough reconnaissance has been made of the portion of the river in which the station is to be located, and details obtained about its accessibility, the proximity of dams or tributaries above or below the station and their probable effects at the station. The following are the chief points to be observed in choosing a discharge site:

(a) The mean velocity of the water should not be less than 0.25 metres per second and it is much better if it does not fall below 0.5 metres per second.

(b) The upper limit of the velocity depends on the equipment available. With the equipment used on the Main Nile where a launch has to be anchored at the various points where the velocity is measured, the observations are fairly easy to carry out when the mid-depth velocity does not exceed about 2 metres per second; but the difficulty increases rapidly as the velocity increases beyond this value. Even at mid-depth velocity of 0.5 metres per second, it is very difficult to keep the launch anchored and take the observations accurately.

(c) At the discharge site, there should be no very obvious turbulence and the stream lines should be as nearly as possible parallel and perpendicular to the line of observation points. This condition is easily secured by having a straight reach of the river upstream of the site and no tributaries entering in this reach.

(d) Across the actual discharge section, the depth of the river should not alter rapidly, otherwise the number of observations required will be very greatly increased and there will be greater risk of turbulence.

Instruments and equipment:

7. The establishment and maintenance of a discharge station require the use of the following instruments and equipment:

- (a) A boat (or launch during the flood stage), fitted with winch and jib for lowering and raising the sounding weight and currentmeters.
- (b) Gurley currentmeters (two small size for low stage and two medium size or small size fitted with penta heads for flood stage), complete with cable connections.
- (c) Four conical sounding weights (two - 10 kilograms and two - 48 kilograms for flood stage).
- (d) Two box-sextants.
- (e) Two stop watches.
- (f) One 20 - metre steel tape.
- (g) 75 metres of 1.6 mm diameter piano wire in three 25-metre lengths (one spare) for suspension of the currentmeter and sounding weight.

Depth-velocity curve method:

8. This method requires the determination of the distribution of velocity in depth at a number of points across the section. At each point, the sounding is made in the usual way. Velocity observations are then taken by currentmeter at 5 selected points on the vertical, the first and last being about 0.5 metres from the surface and bottom respectively and the other three equally spaced. It is usual to make the duration of each of the velocity observations one minute only as even so, considerably more time is required than for the half-depth method.

Half-depth method:

9. In this method velocity observations are made at mid-depth at the sounding points allowing three runs of a minute each at every point. This length of observation time is necessary to reduce the effect of variability of velocity. The choice of the half-depth method instead of depth-velocity curve method is due to the need to reduce the time of observation to a reasonable length. With a parabolic velocity distribution the mean velocity in a vertical is found at approximately 0.6 of the depth below the surface. The half-depth point is chosen instead of the point at 0.6 of the depth, because the vertical change of velocity is less at this point and so the effect of displacement of the currentmeter is less, and also because there is less liability of mistakes being made in the setting of the depth of the meter.

Conversion factor to convert half-depth velocity to mean velocity:

10. The standard practice in making river discharge measurements on the Nile is to depend on velocity observations at half-depth only and apply a conversion factor 0.96 to reduce half-depth velocity to mean velocity. This factor was obtained from over 500 observations on the Main Nile where velocity measurements were made at a number of points on each vertical including that at half-depth.

Errors of the Method of Measuring the Discharge

Errors in the measurement of soundings:

11. In shallow slow flowing streams soundings can be made with a graduated pole, but at most gauging points in the Nile Basin the water is too deep for this to be convenient. The sounding apparatus consists of a 20-metre length of 1.6 millimetre diameter piano wire wound on a winch and 48 or a 10 kilogram conical sounding weight. The heavy weight is used during the flood stage of the river and the light one during the low stage. The winch has two dials and pointers which can be set so that the reading on the dial gives the depth of the water. One dial reads by divisions of 5 centimetres up to 1 metre, and the second by divisions of 1 metre from 0 to 20 metres.

12. In deep rapid water owing to the sounding weight being carried downstream and the suspension wire being curved by the pressure of the flowing water, the observed sounding needs a correction to reduce it to the true depth. This was investigated by Phillips (2) who performed experiments to determine the corrections. A sounding weight was suspended over the side of a launch and towed through the deep still water of the Asswan Reservoir at various lengths of wire. The speed of the launch length of sounding wire and the inclination of the sounding wire to the vertical at the surface are measured. By this means the form of the sounding wire for various speeds and various length was experimentally determined.

13. Phillips' conclusion was that on a good discharge site on the Main Nile at the top of the flood, the correction for exaggerated soundings might be as much as 1%.

Sounding corrections:

14. Corrections (given in centimetres) to be subtracted from apparent soundings.

(A 43 Kg. conical sinker suspended on a steel piano wire 1.6 mm in diam. was used).

Apparent Sounding in Metres:		5 metres	10 metres	15 metres
Mid-depth velocity metre per second	1.5	0	2	6
	2.0	0	5	16
	2.5	2	12	39
	3.0	4	24	74

It appears from the above Table that it is only in deep swift rivers that any corrections to soundings are necessary with the above mentioned sounding apparatus. On the Nile they are only required on the Blue Nile and Main Niles and Atbara at the top of the flood. The effect increases with the thickness of the cable and will operate over a wider range if the cable supporting the currentmeter and sinker is used for sounding.

Errors in the measurement of velocity:

15. Currentmeters are supplied with a standard rating curve by the makers. The rating consists in measuring the number of revolutions per minute corresponding to a given speed of flow of the water. It is necessary, however, to re-rate the meter from time to time, since bearings get worn and rotors sometimes get dented. At the beginning Hurst rated the currentmeter by suspending it from a small pontoon and pulling it backwards and forwards by means of winches in a tank. Later Phillips used a run of more than 100 metres in a disused tank. A trolley was fitted with a chronograph on which were recorded electrically the number of revolutions and the time taken over a fixed distance. The trolley ran on rails and was pushed by a man. This apparatus gave consistent results which agreed well with the maker's standard rating, but the pontoon method, owing probably to turbulence set by the pontoon, gave too many revolutions in a given distance leading to discharges of the order of 2 per cent lower than are given by trolley ratings, but this effect could be reduced by a better design of pontoon. Finally a rating station (3) was set up at the Delta Barrage with a tank 100 metres long, 2 metres wide and 2 metres deep. A trolley spans the tank and runs on rails on the side walls with the meter suspended in the water below. The trolley is driven by a motor and can be run at any speed, from just perceptible motion of 5 centimeters per second to 3 metres per second. (Ward Lamard speed control). The speed of the trolley and number of revolutions of the currentmeter are recorded on a chronograph thus the rating is independent of the observer.

16. In the Price pattern currentmeter the rating curve is a straight line over the range velocities encountered on the Nile. If currentmeters are carefully handled and cleaned and dried after a measurement, rating curves do not vary very much. However, a blunt pivot or one which has been allowed to rust can produce departures from the rating-curve which are important at low velocities such as 0.3 metres per second or less. More serious errors can be produced if the rotating cups are dented as a result of an accident.

17. The practice is to re-rate a meter after every 100 hours of work, then clean it and make any repairs or adjustments and re-rate it. A log book is kept for every meter.

Effect of turbulence on the rating of the currentmeter:

18. In the past there was much controversy as to whether the rating of a currentmeter in still water could be accurate when the instrument is used in flowing water where the flow departs to a greater or less extent from stream line flow in parallel lines. In the Price type of meter, turbulent flow variable in magnitude and direction would tend to exaggerate the velocity. This important question was finally settled by comparison of the Asswan Dam sluice discharge with the discharge measurement of the river at Asswan as given by currentmeter measurement at Khamnaq (later known as Gaafra), 35 kilometres downstream. The sluices have been calibrated by means of a large masonry tank (x)

(x) This tank was built below the Dam to form a water cushion for the protection of the rock surface from the action of the high level sluices.

22000 cubic metres capacity so that the method depends directly on the measurement of volume. This method which is considered as the most accurate which has so far been used to measure the discharge of a large river is fully described in the Papers presented to the Institution of Civil Engineers (5,6).

Comparison of currentmeter and sluices discharge measurements:

19. Several hundred comparisons showed that the methods gave identical results up to about 2000 cubic metres per second at which the mean velocity is about 0.7 metres per second. From 2000 m³/sec. (mean velocity 1 metre per second) the currentmeter measurements on the average were 1 per cent higher than the sluices while at higher discharges the difference was about 2 per cent.

20. The conclusion is that:

- (a) By the direct measurement of water by means of the large tank at Asswan, Egypt had a fundamental and absolute method which provides a standard with which the ordinary method of measurement by means of currentmeters can be compared.
- (b) At all discharge sites on the Nile and its tributaries currentmeters of the Price type (cup type) are very reliable for the measurement of the velocity of flowing water and only very exceptionally would results be slightly exaggerated.

Effect of rocking of the observation boat:

21. The effect of rocking the discharge boat on the velocity was investigated by Phillips. Both a cup type and a propeller type meter were tested. At low and medium velocities of towing the effect of rocking was serious on both cup and propeller type. For example at 0.5 metre per second, a very usual velocity on the Nile and its tributaries, the effect on both meters was about 11 per cent, but in the case of the cup type meter the number of revolutions per second was increased and in the case of the propeller type it was decreased. The effect decreases with increase of horizontal velocity, but is not negligible in the case of the meter at velocities of 2 metres per second (Nile in flood). Obviously rough windy weather should be avoided when measuring discharges from a boat.

22. Mr P. R. Black, formerly Director of Research, Nile Control Department has designed a currentmeter of the cup type with a rotor like the Savonius S-rotor used on windmills. This rotor is robust and easily made, and moreover is unaffected by up and down motion caused by the rocking of the discharge boat, which may be part cause of the slightly higher results given by the Price meter than by the sluices in flood time.

Computation of discharges:

Gauge-discharge curves (7)

23. When a considerable number of discharges have been observed at a site during the year the practice has been to plot a gauge-discharge curve for the year, distinguishing between rising and falling stages. From the curve the discharges corresponding to

5-day mean gauge are read off and the 10-day means, monthly means, and monthly totals are computed. In some cases, no discharges were observed during a particular year but the river gauges were read regularly; a general gauge-discharge curve is then constructed from all the discharges observed at the site and the discharges corresponding to the 10-day mean gauges read off. There are other cases in which discharges have been observed during the year but they are too few in number to construct a reliable gauge-discharge curve. In this case, a general gauge discharge curve is constructed and is then modified to pass the observed points as nearly as possible.

24. There are very few sites in the Nile Basin, except where there are cataracts, where the gauge discharge relation is permanent over long intervals of time. Effects are caused by changes of river bed and are greatest at low stage, and on those rivers where the low discharge is only a small fraction of the flood discharge and the low river winds about in a wide sandy or gravelly bed.

25. At gauge sites near the junctions with tributaries back-water effects cause loops to occur on the gauge discharge curves, with great variations from year to year. Loops also occur where there is spilling over the banks and a return later assisted by rain on the plains, as in the case on the Sobat.

Attempts to fit equations to find the discharge of the Nile (8):

26. Many unsuccessful attempts were made to fit equations to gauge discharge curves of smooth and regular shape. At some stations fairly regular curves are obtained but a curve without any irregularities is rare.

27. For natural streams with irregular beds the relation between discharge and depth can sometimes be represented by a formula of the type:

$$Q = c w h^m$$

but the values of (m) and (c) vary from site to site even on the same stream also from year to year.

Where there is a correlation between (h) and (s) as is often the case of natural water courses, a formula of the form

$$Q = a h^p s^q$$

can sometimes be found, but it is not unique as to (p) and (q) because of the correlation between (h) and (s).

28. The conclusions from the investigation were that general formulae derived from experiments on regular channels such as canals may not represent the facts even approximately on natural channels.

Measurement of the suspended matter in the Nile (9)

29. When in flood the Nile annually brings down in suspension quantities of silt from the volcanic highlands of Ethiopia and the problems of its deposition in the Asswan Reservoir has been the subject of a great deal of study in connection with its use for flood protection or for maintaining a head on the dam in flood for power generation.

30. Systematic collection of samples for the determination of the quantity of silt in suspension in the Nile were made by the Physical Department and later by the Nile Control Department almost uninterruptedly since 1929. Mechanical analyses to determine the quality of silt were also made.

31. The observations were taken to Wadi Halfa or Kajnarty at the tail of the reservoir about 360 kilometres above the Dam and at Gaafra some 30 kilometres below the Dam.

32. The silt content is measured in parts per million by weight and is separated by a sedimentation process into sand and clay. For the whole flood, the proportion of constituents are:

Coarse sand	(0.2-2 m/m)	non or trace
Fine sand	(0.02-0.2 m/m)	30%
Silt	(0.002-0.02 m/m)	40%
Clay	(less than 0.002 m/m)	30%

33. The samples show that the suspended matter increases slowly from the water surface downwards until about 0.65 the depth of the water and then increases fairly rapidly. The sand concentration rises to a maximum at 0.8 the depth and falls off again at lower depth, while the clay and silt are fairly constant throughout the whole depth.

34. The concentration figures vary from 50 to a maximum of about 5400 per million by weight or about ½ per cent while the average for the whole flood is about 1500 parts per million. This is much less than that carried by many rivers like the Colorado, the Yellow and North China rivers and the Kosi river. The Yellow and North China rivers, whose drainage area is mainly composed of highly erodible loess have a silt content during flood as high as 46 per cent by weight.

35. The total annual suspended silt carried by the Nile - as measured at the tail of the Asswan Reservoir - is only 110 million tons as compared with a total silt run-off of 1890 million tons for the Yellow river.

Forecasting the River (10)

36. Two main problems have always occupied the attention of the irrigation engineer in Egypt.

(a) To provide adequate water during the low stage of the Nile for the requirements of cultivation.

(b) To protect the country against the dangers of high floods. Beside heavy damage to crops and property they often brought death and destruction in their wake.

Forecast of the low stage:

37. This is based on the fact that when the rains are well over, the river falls steadily and regularly until the rains start again. Thus in January a forecast can be made of the quantity of the water which will reach Egypt until the end of June, based entirely on the state of affairs in January. The method is based on correlations of gauges or discharges at the different sites on the Nile and its tributaries. They assume amongst other things a regularity of behaviour and regime at similar stages and conditions of the river, an assumption which is generally

true as far as the Nile is concerned. These correlations in conjunction with time of travel relations between the various stations, are found very useful in giving a very fair forecast of the water reaching Asswan during the summer period. The water released day by day from the Asswan Reservoir is governed by these forecasts.

Forecast of the flood stage:

38. At present there is no accurate method of forecasting a high flood until the rain has actually fallen in Ethiopia and then the first warning is given by Roseires gauge, right up the Blue Nile and not far from the Ethiopian mountains where the river shows the effect of the rainfall by rapid fluctuations. In the 620 kilometres from Roseires to Khartoum these rapid fluctuations are considerably damped but the main features persist. And in a high flood what happens on the tributaries is followed day by day in Cairo with the closest attention as on the forecast which is made depend the measures to be taken to reduce the danger from a high flood.

Forecasting the flood from meteorological elements:

39. This has not up to the present attained sufficient accuracy. It is based on the fact that the major features of world weather must be related through the general circulation of the atmosphere and many such relations have been found by Walker, Lyons, Graig, Bliss and Hurst. The Nile flood is one of these major phenomena and Bliss (11) found correlation between the Nile flood, the temperature at Dutch Harbour in Alaska on the borders of the Arctic circle, the temperature in Samoa in the Pacific Ocean and the pressure at Port Darwin in Northern Australia.

where (N) is the Nile flood (Asswan Discharge from July to October)

(D) is the Dutch Harbour mean temperature (March to July)

(S) is the Samoa mean temperature (December to May)

(P) is the Port Darwin mean pressure (March to May)

(D), (S) & (P) represent differences from average divided by the standard deviation.

The formula is:

$$N = 0.40D - 0.23S - 0.30P$$

40. Recent computations by Hurst (12) show that Bliss' coefficients of correlation between the volume of flood and temperature in Alaska and Samoa and the pressure at Port Darwin have decreased from an average of -0.55 to -0.40. Originally Bliss' formula accounted for about half of the variation of the flood and this is now reduced, the rest is due to causes outside those included in the formula. This is within our present experience about as much as this type of research can do. If the flood could be traced to two or three definite causes which could be measured a fairly exact formula could be deduced. Perhaps the great advance in meteorology which has been made as a result of the study of the upper air way lead us to an understanding of the mechanism which produces the Nile flood and so enable long range forecasts of the flood.

Periodicity of the Nile floods:

41. The old records of levels on the Roda gauge in Cairo have

already been mentioned and of these the most complete series give maximum and minimum levels, although with gaps, for about 900 years from 620 to 1520 A.D. They have been analysed by several people in search of periodicities. They found many periods varying from 2 to 240 years. The periodic part is small compared with irregular variations. None of the periods is pronounced enough to be discoverable except by refined and painstaking analysis. A glance at the records when plotted on a fairly large scale shows that there is no period which is directly evident to the eye. It is not a case of Joseph's seven fat and seven lean years, but something much more irregular. The principal feature is the occurrence of fairly long stretches of years when on the whole floods have been high and others when they have been low. Nevertheless a low flood may occur in a high series and high floods in the low series. In the period 1896-1898 floods were high, while 1899-1949 was a period of low floods.

REFERENCES

1. Physical Department, Ministry of Public Works, Handbook of Instructions for Discharge Observers in Egypt and the Sudan, Government Press, Cairo (1929).
2. Phillips, P. An Experiment to Determine Corrections to Soundings in River Gauging. Physical Dept. Paper No. 18, Government Press, Cairo (1925).
3. Phillips, P. Experiments on the Rating of Current Meters Physical Dept. Paper No. 14, Government Press, Cairo (1924).
4. Nil
5. MacDonald, Sir Murdoch, Hurst H.E. & Watt, D.A.F. The Measurement of the Discharge of the Nile through the Sluices of the Asswan Dam. / Proc. Inst. C.E., Vol. 212 / Min. p. 228 (1920-21) and Vol. 218, p. 113 (1923-24) Part II.
6. Hurst, H.E. & Watt, D.A.F., The Similarity of Motion of Water through Sluices and Scale Models Experiments with Models of Sluices in the Asswan Dam., Proc. Inst. C.E., Vol. 218, p.72 (1923-24).
7. Hurst, Black & Simaika, The Nile Basin, Vols. V, VII, & IX, Government Press, Cairo.
8. Hurst, H.E., Measurement and Utilization of the Water Resources of the Nile Basin. Min. Proc. Inst. C.E. Hydraulics Paper No 2, Except Part III (1954)
9. Simaika, Y.M., The Suspended Matter in the Nile Physical Dept. Paper No 40 Govt. Press, Cairo, (1940).
10. Simaika, Y.M., The Regime of the Nile and the Use of Forecasts, United Nations Scientific Conference on the Conservation and Utilization of Resources Lake Success. (1949).
11. Bliss, E.W., Nile Flood and World Weather, Memoirs of the Royal MetP SocP Vol I, No. 5, (1927).
12. Hurst, H.E., The Nile, Constable, London - Revised Edition (1957).